LINAC

SECTION III CHAPTER 01
OF THE FERMILAB SAD

Revision 1 August 7, 2023

This Chapter of the Fermilab Safety Assessment Document (SAD) contains a summary of the results of the Safety Analysis for the Linac segment of the Fermilab Main Accelerator that are pertinent to understanding the risks to the workers, the public, and the environment due to its operation.

SAD Chapter Review

This Section III, Chapter 01 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD), *Linac*, was prepared and reviewed by the staff of the AD/BD/PS in conjunction with the Environment, Safety & Health Division (ESH) Accelerator Safety Department.

Signatures below indicate review of this Chapter, and recommendation that it be approved and incorporated into the Fermilab SAD.

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SAD Review Subcommittee Chair

Revision History

Printed versions of this Chapter of the Fermilab Safety Assessment Document (SAD) may not be the currently approved revision. The current revision of this Chapter can be found on ESH DocDB #1066 along with all other current revisions of all Chapters of the Fermilab SAD.

Author	Rev. No.	Date	Description of Change
CY. Tan Salah Chaurize Mike Wesley	1	August 7, 2023	• Updated to incorporate updated SAD Layout • Incorporation of Risk Matrix tables and hazard discussion
William Pellico Fernanda G. Garcia	0	March 18, 2013	Initial Release of the Linac Accelerator Chapter for the Fermi National Accelerator Safety Assessment Document (SAD)

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Acronyms and Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ACNET	Accelerator Control Network System
AD	Accelerator Directorate
AHJ	Authority Having Jurisdiction
ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
APS-TD	Applied Physics and Superconducting Technology Directorate
ARA	Airborne Radioactivity Area
ASE	Accelerator Safety Envelope
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASO	Accelerator Safety Order, referring to DOE O 420.2D *Safety of Accelerators*
^{7}Be	Beryllium-7
BLM	Beam Loss Monitor
BNB	Booster Neutrino Beam
BPM	Beam Position Monitor
BY	Boneyard
CA	Controlled Area
CA	Contamination Area
CAS	Contractor Assurance System
CC	Credited Control
CCL	Coupled Cavity Linac
CDC	Critical Device Controller
CERN	European Organization for Nuclear Research
CFM	Cubic Feet per Minute
CFR	Code of Federal Regulations (United States)
Ci	Curie
CLW	Co-Located Worker (the worker in the vicinity of the work but not actively participating)
cm	centimeter
CPB	Cryogenics Plant Building
CSO	Chief Safety Officer
CUB	Central Utility Building
CW	Continuous Wave
CX	Categorically Excluded
D&D	Decontamination and Decommissioning
DA	Diagnostic Absorber
DAE	Department of Atomic Energy India
DCS	Derived Concentration Standard
DocDB	Document Database
DOE	Department of Energy
DOT	Department of Transportation
DR	Delivery Ring

DSO	Division Safety Officer
DSS	Division Safety Specialist
DTL	Drift Tube Linac
DUNE	Deep Underground Neutrino Experiment
EA	Environmental Assessment
EA	Exclusion Area
EAV	Exhaust Air Vent
EENF	Environmental Evaluation Notification Form
EMS	Environmental Management System
EOC	Emergency Operations Center
EPA	Environmental Protection Agency
ES&H	Environment, Safety and Health
Fermilab	Fermi National Accelerator Laboratory, see also FNAL
FESHCom	Fermilab ES&H Committee
FESHM	Fermilab Environment, Safety and Health Manual
FHS	Fire Hazard Subcommittee
FIRUS	Fire Incident Reporting Utility System
FNAL	Fermi National Accelerator Laboratory, see also Fermilab
FODO	Focus-Defocus
FONSI	Finding of No Significant Impact
FQAM	Fermilab Quality Assurance Manual
FRA	Fermi Research Alliance
FRCM	Fermilab Radiological Control Manual
FSO	Fermilab Site Office
FW	Facility Worker (the worker actively performing the work)
GERT	General Employee Radiation Training
GeV	Giga-electron Volt
^{3}H	Tritium
HA	Hazard Analysis
HAR	Hazard Analysis Report
HCA	High Contamination Area
HCTT	Hazard Control Technology Team
HEP	High Energy Physics
HFD	Hold for Decay
HLCF	High Level Calibration Facility
HPR	Highly Protected Risk
Hr	Hour
HRA	High Radiation Area
HSSD	High Sensitivity Air Sampling Detection
HVAC	Heating, Ventilation, and Air Conditioning
HWSF	Hazardous Waste Storage Facility
Hz	Hertz
IB	Industrial Building
IBC	International Building Code
ICW	Industrial Cooling Water

IEPA	Illinois Environmental Protection Agency
IEEE	Institute of Electrical and Electronics Engineers
INFN	Istituto Nazionale di Fisica Nucleare
IMPACT	Integrated Management Planning and Control Tool
IPCB	Illinois Pollution Control Board
IQA	Integrated Quality Assurance
ISD	Infrastructure Services Division
ISM	Integrated Safety Management
ITNA	Individual Training Needs Assessment
KeV	kilo-electron volt
kg	kilo-grams
kW	kilo-watt
LBNF	Long Baseline Neutrino Facility
LCW	Low Conductivity Water
LHC	Harge Hadron Collider
LLCF	Low Level Calibration Facility
LLWCP	Low Level Waste Certification Program
LLWHF	Low Level Waste Handling Facility
LOTO	Lockout/Tagout
LPM	Laser Profile Monitor
LSND	Liquid Scintillator Neutrino Detector
LSO	Laser Safety Officer
m	meter
mA	milli-amp
MABAS	Mutual Aid Box Alarm System
MARS	Monte Carlo Shielding Computer Code
MC	Meson Center
MC&A	Materials Control and Accountability
MCR	Main Control Room
MEBT	Medium Energy Beam Transport
MEI	Maximally Exposed Individual
MeV	Mega-electron volt
MI	Main Injector
MINOS	Main Injector Neutrino Oscillation Search
MMR	Material Move Request
MOI	Maximally-Exposed Offsite Individual *(Note: due to the Fermilab Batavia Site being open to the public, the location of the MOI is taken to be the location closest to the accelerator that is accessible to members of the public.)*
MP	Meson Polarized
mrad	milli-radian
mrem	milli-rem
mrem/hr	milli-rem per hour
MT	Meson Test
MTA	400 MeV Test Area
MTF	Magnet Test Facility

^{22}Na	Sodium-22
NC	Neutrino Center
NE	Neutrino East
NEC	National Electrical Code
NEPA	National Environmental Policy Act
NESHAPS	National Emissions Standards for Hazardous Air Pollutants
NFPA	National Fire Protection Association
NM	Neutrino Muon
NMR	Nuclear Material Representative
NOvA	Neutrino Off-axis Electron Neutrino (ve) Appearance
NPH	Natural Phenomena Hazard
NRTL	Nationally Recognized Testing Laboratory
NIF	Neutron Irradiation Facility
NTSB	Neutrino Target Service Building, see also TSB
NuMI	Neutrinos at the Main Injector
NW	Neutrino West
ODH	Oxygen Deficiency Hazard
ORC	Operational Readiness Clearance
OSHA	Occupational Safety and Health Administration
pCi	pico-Curie
pCi/mL	pico-Curie per milliliter
PE	Professional Engineer
PIN	Personal Identification Number
PIP	Proton Improvement Plan
PIP-II	Proton Improvement Plan - II
PHAR	Preliminary Hazards Analysis Report
PPD	Particle Physics Directorate
PPE	Personnel Protective Equipment
QA	Quality Assurance
QAM	Quality Assurance Manual
RA	Radiation Area
RAF	Radionuclide Analysis Facility
RAW	Radioactive Water
RCT	Radiological Control Technician
RF	Radio-Frequency
RFQ	Radio-Frequency Quadrupole
RIL	RFQ Injector Line
RMA	Radioactive Material Area
RMS	Root Mean Square
RPCF	Radiation Physics Calibration Facility
RPE	Radiation Physics Engineering Department
RPO	Radiation Physics Operations Department
RRM	Repetition Rate Monitor
RSI	Reviewed Safety Issue
RSIS	Radiation Safety Interlock System

RSO	Radiation Safety Officer
RWP	Radiological Work Permit
SA	Shielding Assessment
SAA	Satellite Accumulation Areas
SAD	Safety Assessment Document
SCF	Standard Cubic Feet
SCFH	Standard Cubic Feet per Hour
SEWS	Site-Wide Emergency Warning System
SNS	Spallation Neutron Source
SR	Survey Riser
SRF	Superconducting Radio-Frequency
SRSO	Senior Radiation Safety Officer
SSB	Switchyard Service Building
SSP	Site Security Plan
SWIC	Segmented Wire Ionization Chambers
TLM	Total Loss Monitor
TLVs	Threshold Limit Values
TPC	Time Projection Chamber
TPES	Target Pile Evaporator Stack
TPL	Tagged Photon Lab
TSB	Target Service Building, see also NTSB
TSCA	Toxic Substances Control Act
TSW	Technical Scope of Work
T&I	Test and Instrumentation
UPB	Utility Plant Building
UPS	Uninterruptible Power Supply
USI	Unreviewed Safety Issue
VCTF	Vertical Cavity Test Facility
VHRA	Very High Radiation Area
VMS	Village Machine Shop
VMTF	Vertical Magnet Test Facility
VTS	Vertical Test Stand
WSHP	Worker Safety and Health Program
µs	micro-second

III-1. Linac

III-1.1. Introduction

This Section III, Chapter 01 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the Linac segment of the Fermilab Main Accelerator.

III-1.1.1 Purpose/Function

The purpose of the Linac accelerator is to accelerate H- ion beam from rest energy to 400 MeV. There are two possible beam energies and five possible extraction areas that Linac beam can be extracted. Beam can be extracted at 66 MeV towards the Neutron Therapy Facility (NTF) and the remaining four areas are at 400 MeV. These areas are Booster synchrotron accelerator, the MeV Test Area (MTA) and two Linac beam absorbers.

III-1.1.2 Current Status

The Linac segment of the Fermilab Main Accelerator is currently: **Operational**.

III-1.1.3 Description

The Linac accelerator includes the Radio Frequency Injector (RIL) at the north end of the enclosure followed by approximately 200 meters of accelerating cavities and transfer line components to transport beam to four different areas (Figure 1). An associated equipment gallery is located above and to the east of the enclosure floor level.

The RIL is composed of two 35 keV magnetron sources followed by a 750 keV Radio Frequency Quadrupole (RFQ). The line uses conventional technology such as solenoids, a buncher cavity, quadrupoles, and steering magnets to match into the Linac. The H- ion beam is then accelerated to 116 MeV by five 201.25-MHz Drift Tube Linac (DTL) tanks and to 400 MeV by seven 805- MHz Coupled Cavity Linac (CCL) cavities. The Linac pulses at a 15 Hz repetition rate but the actual beam cycle rate is dependent upon the users. The average beam current in the Linac is **< 30 mA**.

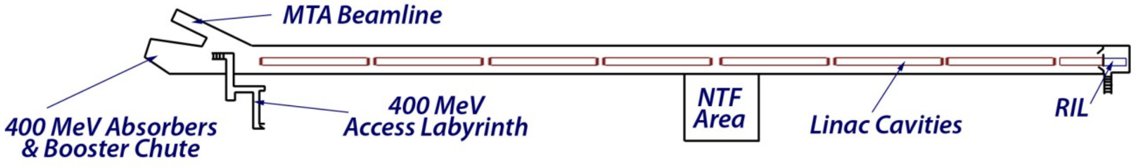

Figure 1: Linac overview.

The Linac utilizes approximately 30 beam position monitors (BPMs), 30 beam loss monitors (BLMs), and 20 beam toroids that measure the beam current. The Linac also utilizes one emittance probe at the 10 MeV region and approximately a dozen single-wire scanners located along the high energy Linac for beam control. Linac diagnostics are typically located between the DTL and CCL accelerator cavities.

III-1.1.4 Location

The Linac segment of the Fermilab Main Accelerator is located on the Fermilab site in Batavia, IL.

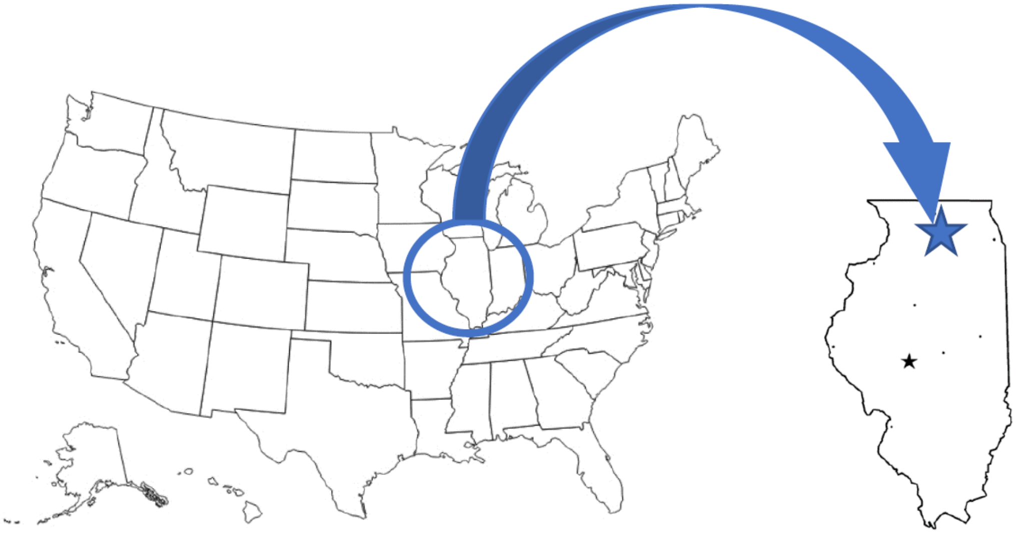

Figure 2. Regional view showing the location of the Fermilab site in Batavia, IL.

The Linac is located in the central campus on the Fermilab site. See Figure 3.

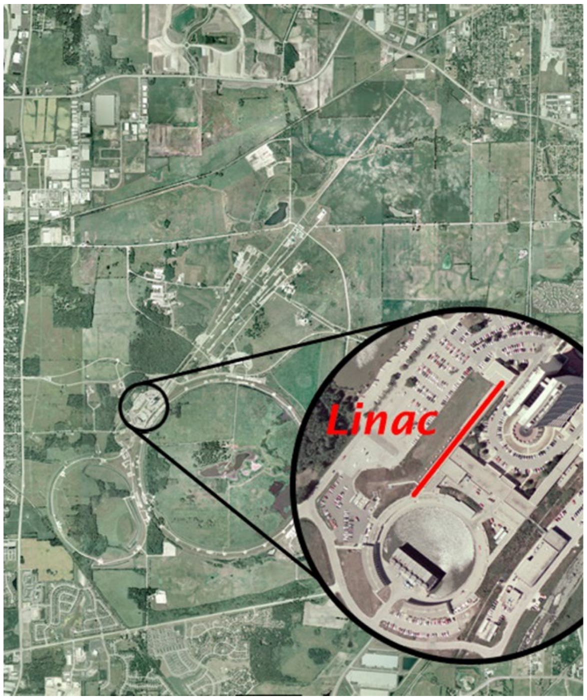

Figure 3. Aerial view of the Fermilab site, indicating the location of the Linac.

III-1.1.5 Management Organization

The Beams Division/Proton Source/Linac Group is responsible for the operation and maintenance of all Linac RF cavities, RF generators, power supplies, and instrumentation with support from the Accelerator Complex Technology Division. The Beams Division Operations Department monitors the state of the Linac from the MCR at all times and requests assistance from the Linac Group when there are deviations from normal operating conditions. Building infrastructure is maintained by the Infrastructure Services Directorate.

III-1.1.6 Operating Modes

The RIL extracts H- beam and accelerates to 750 keV from the source on a 15 Hz duty cycle. When the beam permit system allows, the Preacc Pulse Shifter module syncs the timing of the RIL to match the 1st Linac RF cavity and beam is accelerated in the Linac. If there is no permit, beam arrives at the Linac when there is no RF present in the cavities and dissipates. This is known as a Standby Pulse. There are four accelerating modes of Linac operation:

- High Energy Physics (HEP) beam (Figure 4): This is the primary mode of operation where beam is accelerated to 400 MeV and extracted to the Booster synchrotron via an electrostatic chopper to the field region of the Booster Lambertson. For every 2.2 us of H- beam a laser is fired to neutralize a small portion of beam. The neutral beam is not accelerated and provides space for Booster beam manipulations. The repetition rate and pulse length are configurable up to 15 Hz and 44 us, respectively. Beam current is dependent on conditions in the source but is typically from 20 to 25 mA.
- MTA beam (Figure 4): The MTA beamline provides beam to the Irradiation Test Area (ITA) which is a 400 MeV fixed-target experimental enclosure. Additionally, the MTA beamline can be used to evaluate Linac emittance at 400 MeV. Beam is directed to the MTA beamline by two pulsed C-magnets before and after the electrostatic chopper. MTA is limited to 2.7E15 protons/hr. and can extract up to eight 15 Hz Linac pulses once a minute.
- NTF beam: The NTF beam line provides 66 MeV beam to the Neutron Irradiation Facility (NIF). NIF can request up to 15 Hz of 64 us beam but is typically subordinate to requests for HEP beam. During NTF beam cycles only the first three drift tube cavities are used for acceleration, beam coasts through the fourth cavity, and is extracted to the NTF beam line by a 38° dipole magnet.
- Linac Studies (Figure 4): To evaluate 400 MeV beam or check proper functioning of equipment, Linac output can be directed to one of two beam dumps. The most common mode of operation utilizes a dipole magnet to direct beam to the momentum dump which can dissipate 10 kW of beam power; the maximum output of the Linac. Linac Studies pulses can be requested at 15 Hz up to 80 us width.

Figure 4 shows the end of Linac enclosure area with the 400 MeV transfer line to Booster, the MTA extraction line, and the two possible beam absorbers for Linac beam. Table 1 presents a summary of all available Linac beam operational modes.

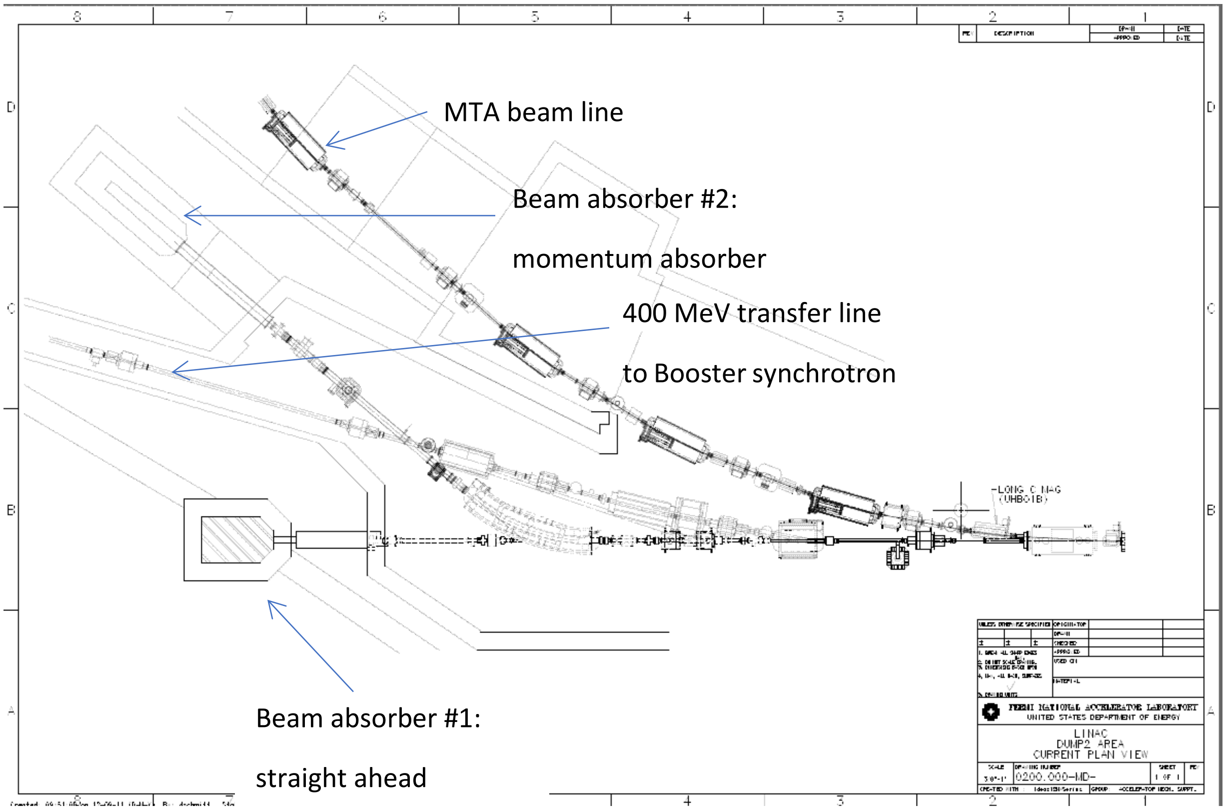

Figure 4: Linac 400 MeV extraction areas, two beam absorbers, 400 MeV transfer line to Booster and MTA extraction line are indicated here.

Table 1: Linac operational modes.

Operational mode	Approximate intensity	Extraction line
HEP mode (beam to Booster synchrotron)	2.2 - 44.4 μs of < 30 mA. Rate depends upon HEP program (Up to 15 Hz is expected)	400 MeV transfer line (The first 2 μs of each HEP beam pulse goes to the 400 MeV beam absorber)
MTA mode	Up to 2.7E15 protons per hour	MTA beamline
Linac tune-up	Depends upon HEP program but up to 15Hz at full pulse width of ~80 μs	400 MeV beam absorber
NTF mode	Linac beam pulse width 64 μs Rate depends upon HEP program – up to 15 Hz	NTF beamline – after DTL tank 4

III-1.1.7 Inventory of Hazards

The following table lists all of the identified hazards found in the Linac enclosure and support buildings. Section III-1.10 *Appendix – Risk Matrices* describes the baseline risk (i.e., unmitigated risk), any preventative controls and/or mitigative controls in place to reduce the risk, and residual risk (i.e., mitigated risk) for facility worker, co-located worker and Maximally Exposed Offsite Individual (MOI) (i.e., members of the public). A summary of these controls is described within Section III1.2 *Safety Assessment.*

Prompt ionizing, Oxygen Deficiency Hazards due to cryogenic systems within accelerator enclosures, and Fluorinert byproducts due to use of Fluorinert that is subject to particle beam have been identified as accelerator specific hazards, and as such their controls are identified as Credited Controls. The analysis of these hazards and their Credited Controls will be discussed within this SAD Chapter, and their Credited Controls summarized in the Accelerator Safety Envelope for the Fermilab Main Accelerator. Accelerator specific controls are identified as **purple/bold** throughout this Chapter. Cryogens are not present in quantities sufficient to present an ODH hazard for Linac areas.

All other hazards present in Linac areas are safely managed by other DOE approved applicable safety and health programs and/or processes, and their analyses have been performed according to applicable DOE requirements as flowed down through the Fermilab Environment, Safety and Health Manual (FESHM). These hazards are considered to be Standard Industrial Hazards (SIH), and their analysis will be summarized in this SAD Chapter.

Table 2. Hazard Inventory for Linac.

Radiological		**Toxic Materials**	
☒	**Prompt Ionizing Radiation**	☒	Lead
☒	Residual Activation	☒	Beryllium
☒	Groundwater Activation	☐	**Fluorinert & Its Byproducts**
☐	Surface Water Activation	☐	Liquid Scintillator Oil
☐	Radioactive Water (RAW) Systems	☐	Ammonia
☐	Air Activation	☐	Nanoparticle Exposures
☐	Closed Loop Air Cooling	**Flammables and Combustibles**	
☐	Soil Interactions	☒	Combustible Materials (e.g., cables, wood cribbing, etc.)
☒	Radioactive Waste	☒	Flammable Materials (e.g., flammable gas, cleaning materials, etc.)
☒	Contamination	**Electrical Energy**	
☐	Beryllium-7	☒	Stored Energy Exposure
☐	Radioactive Sources	☒	High Voltage Exposure
☐	Nuclear Material	☒	Low Voltage, High Current Exposure
☐	Radiation Generating Devices (RGDs)	**Kinetic Energy**	
☒	Non-Ionizing Radiation Hazards	☒	Power Tools
Thermal Energy		☒	Pumps and Motors
☒	Bakeout	☒	Motion Tables
☒	Hot Work	☐	Mobile Shielding
☒	**Cryogenics**	**Magnetic Fields**	
Potential Energy		☒	Fringe Fields
☒	Crane Operations	**Other Hazards**	
☒	Compressed Gasses	☒	Confined Spaces
☒	Vacuum/Pressure Vessels/Piping/Piping	☒	Noise
☒	Vacuum Pumps	☒	Silica
☒	Material Handling	☒	Ergonomics
Access & Egress		☒	Asbestos
☒	Life Safety Egress	☒	Working at Heights

III-1.2. Safety Assessment

All hazards for the Linac segment of the Fermilab Main Accelerator are summarized in this section, with additional details of the analyses for accelerator specific hazards.

III-1.2.1 Radiological Hazards

The Linac presents radiological hazards in the form of a list of checked off radiological hazards shown in Table 2. Detailed shielding assessments in references [2],[3] address these hazards and provide a detailed analysis of the facility demonstrating the required shielding, controls and interlocks to comply with the Fermilab Radiological Control Manual (FRCM)[1].

After completion of the risk analysis shown in tables 2.1-2.3, the baseline risk level RI has been reduced to a residual risk level of RIII.

III-1.2.1.1 Prompt Ionizing Radiation

Ionizing radiation due to beam loss is a primary concern for beam transported through the Linac enclosure. In order to protect workers and the general public, the enclosures and beam pipes are surrounded either by sufficient amounts of shielding (earth, concrete or iron), and/or networks of interlocked detectors to keep any prompt radiation within acceptable levels. Operation of the area conforms to the FRCM to maintain exposures for operating personnel ALARA.

The assessment requires that:

- All penetrations be filled with shielding as specified.
- All movable shielding blocks be installed as specified.
- All interlocked detectors be installed as specified.
- The radiation safety interlock system be certified as working.
- The average beam intensity in the Linac is limited to 3.54 x 10^{17} protons per hour in the form of 35 mA pulses of 30 μs duration repeated at a frequency of 15 Hz.

The Linac Shielding Assessment concludes

- The facility is in conformance with all FRCM requirements and can be operated safely with the following beam parameters:
    - Maximum intensity is 3.54 x 10^{18} protons per hour;
    - Maximum energy is 400 MeV;
    - Annual limit of 6.4 x 10^{20} protons to either the straight ahead or momentum absorbers.

The RF cavities in the Linac enclosure contain electromagnetic fields of sufficient magnitude to accelerate ‘dark-current’ electrons to energies capable of producing X-ray radiation. The radiation safety interlock system for the Linac disables RF power to the cavities and thereby eliminates the x-ray hazard whenever personnel access the enclosure.

The 201 and 805 MHz RF power sources for the accelerating cavities are also X-ray producing sources. X-ray shielding for the RF amplifier tubes was developed as part of the Linac 400 MeV upgrade project in the 1990’s. Fermilab Radiological Control Technicians (RCT), under the direction of the Accelerator Directorate (AD) Radiation Safety Officer (RSO), have documented that the X-ray level outside the shielding is well below the 0.25 mrem/hr threshold specified in the FRCM for the unlimited occupancy area in which the RF amplifier tubes operate.

III-1.2.1.2 Residual Activation

High intensity beam delivery of ionizing radiation in the Linac will produce activated materials inside the enclosure which can pose a residual radiation hazard to personnel entering the enclosure. The residual dose rate found in the Linac from initial entry surveys is historically less than 5 mrem/hr. Exceptions include some localized losses found at the transition between the DTL and CCL of less than 20 mrem/hr, and at the 400 MeV area at the Linac-extraction Lambertson, which sets the start of the 400 MeV transfer line to the Booster enclosure, of less than 200 mrem/hr.

Access to activated components in the Linac enclosure is tightly controlled. All potential residual activation hazards are handled operationally as in all other primary beam enclosures. These controls include verification of training, centralized authorization, and key entry. The level of control depends on the level of residual radiation. The controls will follow the administrative controls and safety guidelines found in the Radiological Work Permit (RWP). In most cases, the general RWP for accesses will suffice. A job-specific RWP and an as-low-as-reasonably-achievable (ALARA) plan will be required for work on any highly activated equipment with a potential individual exposure greater than 200 mrem or potential job exposure greater than 1000 person-mrem.

III-1.2.1.3 Groundwater Activation

Radioactivity induced by the interaction of high-energy ionizing radiation with the soil that surrounds the beam absorbers is addressed in this section. The production of ^{3}H and ^{22}Na is the greatest concern due to production rate and leachability into the groundwater as well as the long half-lives of the radionuclides. Fermilab standards pertaining to groundwater activation are provided in the FRCM, and the methodologies used for making groundwater activation estimates, are given in Environmental Protection Notes No. 8 [4] and 17 [5]. The methodology is designed to achieve a conservative estimate of groundwater activation. Additionally, the annual integrated intensity used in the calculations is estimated well above the practical beam delivery limits.

Calculations estimating groundwater activation were performed using the MARS Monte Carlo simulation programs for the momentum absorber when the absorber developed an internal vacuum leak. Instead of replacing the absorber, an insert with a titanium window was installed 3 ft. inside the soil shielding. The results indicate a less than 5% effect due to adding the titanium window [6]. The momentum and straight-ahead absorbers are geometrically similar. The calculations show that both absorbers can safely operate at up to 6.4 x 10^{20} protons per year. As shown in Table 3, after 15 years of continuous operation of 6.4 x 10^{20} protons delivered per year to the momentum absorber, an accumulation of ^{3}H and ^{22}Na in the groundwater is significantly less than the regulatory limits defined in the Derived Concentration Standard set forth in Department of Energy (DOE) Order 458.1 (DOE O 458.1).

Ground water activation is not applicable to this area.

Table 3: Momentum absorber groundwater.

Protons Delivered to Target	Projected Concentrations pCi/ml-y	Regulatory Limit Groundwater*[1] pCi/ml-y
6.4x10^{20}	0.12 ^{3}H	20 ^{3}H
	0.0034 ^{22}Na	0.4 ^{22}Na

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[1] The value for ^{3}H in groundwater is taken from the Federal drinking water standards set forth in 40 CFR 141. The value for ^{22}Na is 4% of the DCS of DOE Standard-1196-2011 as set forth by DOE O 458.1.

III-1.2.1.4 Surface Water Activation

See section III-1.2.1.3.

Surface water activation is not applicable to this area.

III-1.2.1.5 Radioactive Water (RAW) Systems

N/A.

III-1.2.1.6 Air Activation

This hazard is not applicable to this area.

III-1.2.1.7 Closed Loop Air Cooling

This hazard is not applicable to this area.

III-1.2.1.8 Soil Interactions

This hazard is not applicable to this area.

III-1.2.1.9 Radioactive Waste

Radioactive waste produced during Linac operations will be managed within the established Radiological Protection Program (RPP) and as prescribed in the Fermilab Radiological Control Manual (FRCM).

Radioactive waste is a standard radiological hazard that is managed within the established Radiological Protection Program (RPP) and as prescribed in the Fermilab Radiological Control Manual (FRCM). Waste minimization is an objective of the equipment design and operational procedures. Although production of radioactive material is not an operational function of the Linac, beam loss and, in the case of some beam diagnostics devices, intentional interception of the beam will result in activation of beam line elements. Reuse of activated items will be carried out when feasible. Activated items that cannot be reused will be disposed of as radioactive waste in accordance with the FRCM requirements.

III-1.2.1.10 Contamination

Although not typically encountered, contamination has been noted occasionally at the 400 MeV extraction region. Personnel are required by the RWP to wear gloves and shoe covers when accessing the CCL and 400 MeV areas of the Linac enclosure.

III-1.2.1.11 Beryllium-7

This hazard is not applicable to this area.

III-1.2.1.12 Radioactive Sources

This hazard is not applicable to this area

III-1.2.1.13 Nuclear Material

This hazard is not applicable to this area

III-1.2.1.14 Radiation Generating Devices (RGDs)

This hazard is not applicable to this area.

III-1.2.1.15 Non-Ionizing Radiation Hazards

Hazardous levels of RF electromagnetic energy are generated by the RF power sources in the Linac. During normal operations, RF energy is contained within waveguides, coaxial transmission lines, or accelerating cavities. The engineering of the RF power sources is sufficient to shield personnel from hazardous levels of non-ionizing radiation. A survey conducted by the ESH Industrial Hygiene group in January of 2023 showed no hazardous fields present in the linac gallery. Specific "Lock-out/Tag-out" procedures are in place to establish safe conditions for personnel working on these systems. RF field surveys are performed on an as-needed basis by the Industrial Hygiene Group.

III-1.2.1.15.1 Laser Notcher

The Booster synchrotron must contain an extraction gap in the Booster beam to provide a beam free region for the extraction kicker rise time to minimize losses at extraction. The Class IV Linac Laser Notcher (LLN) System, installed at the downstream end of the 750 KeV RFQ, is utilized create this extraction gap outside of the Booster tunnel. It accomplishes this goal by neutralizing multiple 80 ns portions of the 201.25 MHz linac bunch train at the Booster revolution period for injection into Booster. The laser system is a Master Oscillator Power Amplifier laser system consisting of a low power CW diode seed laser an arbitrary waveform generator as input to an optical modulator creating the required laser pulse pattern. This laser pulse pattern is then amplified by four specially designed fiber lasers and two final high energy solid state free-space amplifiers and associated optics to deliver the laser into a neutralization interaction cavity to interact with the linac bunches.

Because of the location of the Laser Notcher, it must be operated as a Class I system to prevent any unauthorized access to laser light or accidental exposure of personnel passing through the area. The free space amplifier system, a transport system and a laser dump system are all totally enclosed in light tight enclosures and are interlocked to prohibit accessing the enclosures when the laser is operating. The laser interaction cavity is installed in the accelerator MEBT vacuum system which is interlocked to prohibit any laser beam from being generated, if there is a potential for personnel working on the vacuum system. Local view ports on the upstream of tank 1 have a light tight blanking flange and CAUTION Do Not Remove signage. The Laser Notcher system is interfaced to the Accelerator Division Critical Device Control module which monitors the status of all interlocks and the status of the MEBT vacuum system and if and only if all inputs are made up a permit is issued to the various amplifiers. The interface module between the LLN and the CDC is a local interface chassis which monitors all interlocks and provides the ability to locally enable the permits and allow operation. This module located in the electronics rack for the fiber lasers also contains a CRASH button for removal of the permits to the LN. Prior to initial operation the laser system, a full ORC was performed. The LLN Safety interlock system is regularly tested by the ESH AD Interlock group.

III-1.2.2 Toxic Materials

The Linac presents toxic material hazards in the form of a list of checked off hazards shown in Table 2 of the Table 2. All toxic material hazards present in Linac areas are in the form of Standard Industrial Hazards discussed in SAD Section I, Chapter 04.

III-1.2.2.1 Lead

The primary lead hazard is in the form of lead solder from older electronics still in use. Lead radiation shielding is used in several areas in the Linac, typically in the for of encased lead blankets. Lead exposure in Linac areas have been evaluated within the common Risk Matrix table included in SAD Section I, Chapter 04 Safety Analysis. Work in Linac involving lead implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.2.2 Beryllium

N/A.

III-1.2.2.3 Fluorinert & Its Byproducts

N/A.

III-1.2.2.4 Liquid Scintillator Oil

N/A.

III-1.2.2.5 Pseudocumene

N/A.

III-1.2.2.6 Ammonia

N/A.

III-1.2.2.7 Nanoparticle Exposures

This hazard is not applicable to this area.

III-1.2.3 Flammables and Combustibles

The Linac presents flammable and combustible hazards in the form of a list of checked off hazards shown in Table 2. Unusual hazards are present in the form of flammable hydrogen gas used in the source.

After completion of the risk analysis sown in tables 2.7-2.9, the baseline risk level RI has been reduced to a residual risk level of RIV.

III-1.2.3.1 Combustible Materials

Common combustible materials (paper, wood pallets, etc.) are typically found in the Linac gallery. Combustible materials in Linac areas have been evaluated within the common Risk Matrix table included in SAD Section I, Chapter 04 Safety Analysis. Work in Linac involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.3.2 Flammable Materials

Common industrial lubricants, solvents, and paints are used by linac technicians to maintain equipment and are stored in flammable materials lockers. Most flammable materials present in Linac areas have been evaluated within the common Risk Matrix table included in SAD Section I, Chapter 04 Safety Analysis. Work in Linac involving this hazard implements the controls specified in the common Risk Matrix table.

The injector source utilizes two 30 cubic ft cylinders containing a total of 0.15 kg of highly flammable hydrogen gas. One cylinder will be operational and the other used for the backup injector source. The injector source installation contains less than 0.6 kg or 250 standard cubic feet (SCF) of hydrogen which corresponds to a Flammable Gas Risk Class 0 area in accordance with Fermilab Environment, Safety, and Health Manual (FESHM). The area is appropriately posted with signs “Danger-Flammable Gases, No Ignition Sources”. A contact list of people responsible for the system is posted. All cylinders are appropriately secured and the stored cylinders are kept capped.

Detailed analysis of the hydrogen safety issues and identification of the hazard mitigations are found in “Flammable Gas Risk Calculation and Installation Requirements for Commissioning and Operation of the RFQ Ion Source in the I-Pit” [7].

III-1.2.4 Electrical Energy

The Linac presents electrical energy hazards in the form of a list of checked off hazards shown in Table 2. Unusual hazards are present in the form exposed low voltage, high current conductors used for DTL RF and replacement capacitors in storage.

After completion of the risk analysis sown in tables 2.10-2.12, the baseline risk level RI has been reduced to a residual risk level of R IV.

III-1.2.4.1 Stored Energy Exposure

The Linac electrical hazards from the AC power distribution systems and the power supplies for the beam line magnetic components have been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in Linac involving this hazard implements the controls specified in the common Risk Matrix table. The notable accelerator-specific electrical hazard is the modulators for the high-power RF sources, e.g. the 201 and 805 MHz RF systems. The RF modulators represent sources of high voltage and high stored electrical energy. These hazards are mitigated by containing this equipment in interlocked cabinets and by following Proton Source Department Linac written Lock Out / Tag Out procedures for access to the cabinets and maintenance of the equipment.

Linac RF systems rely on large capacitor banks to create high voltage pulses. Replacement capacitors are stored in the gallery in the event of equipment failures. These capacitors can passively store charge when unattended and present a shock hazard if not properly stored. All spare capacitors are stored with their terminals grounded and kept out of high traffic areas.

III-1.2.4.2 High Voltage Exposure

See previous section III-1.2.4.1.

III-1.2.4.3 Low Voltage, High Current Exposure

Both the 7835 & 4616 power tubes for DTL RF systems have high current filament power supplies with exposed conductors. To protect against incidental contact which may cause burns, insulating guards are in place and cabinet doors where conductors exist are typically closed. Trained electrical workers doing work near low voltage, high current conductors are to remove all metal jewelry and use nonconductive tools. In the event of a metal tool being accidently coming into contact with the conductors, overcurrent protection circuits exist in to limit the incident energy of the arc flash.

III-1.2.5 Thermal Energy

The Linac presents thermal energy hazards in the form of a list of checked off hazards shown in Table 2. All thermal energy hazards present in Linac areas are in the form of Standard Industrial Hazards discussed in SAD Section I, Chapter 04.

III-1.2.5.1 Bakeout

Historically, Linac does not do magnet or beam pipe bakeouts. However, if there is a need to do bakeouts, this hazard has been evaluated within the common Risk Matrix table included in SAD Section I, Chapter 04 Safety Analysis. Work in Linac involving Bakeout implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.5.2 Hot Work

Qualified welders occasionally work in the linac gallery and tunnel to repair waterlines and other metalwork. Hot work in Linac areas has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in Linac involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.5.3 Cryogenics

There are several dewars in the Linac gallery which store liquid nitrogen for vacuum traps in the linac tunnel. The dewars are not of sufficient volume to represent an ODH hazard. These dewars and LN2 handling procedures have been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in Linac involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.6 Kinetic Energy

The Linac presents kinetic energy hazards in the form of a list of checked off hazards shown in Table 2. All kinetic energy hazards present in Linac areas are in the form of Standard Industrial Hazards discussed in SAD Section I Chapter 04.

III-1.2.6.1 Power Tools

Power tools are commonly used when working on Linac equipment and the gallery and tunnel. Power tool use has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in Linac involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.6.2 Pumps and Motors

Standard industrial pumps and motors are utilized throughout the Linac area for water cooling and vacuum systems. These have been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in Linac areas involving pumps and motors implement the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.6.3 Motion Tables

Linac technicians use mechanical motion tables to install equipment and improve ergonomics when conducting maintenance or repairs. Motion tables have been evaluated within the common Risk Matrix table included in SAD Section I, Chapter 04 Safety Analysis. Work in Linac involving motion tables implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.6.4 Mobile Shielding

N/A.

III-1.2.7 Potential Energy

The Linac presents potential energy hazards in the form of a list of checked off hazards shown in Table 2. All potential energy hazards present in Linac areas are in the form of Standard Industrial Hazards discussed in SAD Section I, Chapter 04.

III-1.2.7.1 Crane Operations

Trained technicians utilize various hoists lifts, and bridge cranes to move, maintain, and install equipment in the Linac gallery and tunnel. Crane hazards have been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in Linac involving cranes implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.7.2 Compressed Gasses

Compressed nitrogen, argon, and hydrogen are present in Linac areas to facilitate machine operations. Compressed gas cylinders are stored, used, and moved throughout the Linac gallery and tunnel.

Compressed gas hazards have been evaluated within the common Risk Matrix table included in SAD Section I, Chapter 04 Safety Analysis. Work in Linac involving compressed gas implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.7.3 Vacuum/Pressure Vessels/Piping

Vacuum vessels are present in Linac in the form of beam pipe, RF cavities, and other beamline components. Pressure vessel are present in the form of cryogen storage dewars, RF waveguides, and power amplifier tubes. Vacuum and pressure vessel have been evaluated within the common Risk Matrix table included in SAD Section I, Chapter 04 Safety Analysis. Work in Linac involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.7.4 Vacuum Pumps

Vacuum pumps are used throughout the Linac to maintain vacuum on beamline and RF gene components and This hazard has been evaluated within the common Risk Matrix table included in SAD Section I, Chapter 04 Safety Analysis. Work in Linac involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.7.5 Material Handling

Trained personnel operate forklifts, stackers, and hand carts to move materials throughout the Linac area. DTL power amplifiers can be moved using an air caster system. Additionally, heavy equipment may be moved short distances utilizing team lifts. Individual lifting is limited to items 50 lbs or less. These hazards have been evaluated within the common Risk Matrix table included in SAD Section I, Chapter 04 Safety Analysis. Work in Linac involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.8 Magnetic Fields

The Linac presents magnetic field hazards in the form of a list of checked off hazards shown in Table 2. Unusual hazards are present in the form fringe fields which may interfere with implanted medical devices

After completion of the risk analysis sown in tables 2.22-2.24, the baseline risk level RI has been reduced to a residual risk level of RIII.

III-1.2.8.1 Fringe Fields

The fringe field hazard mainly comes from powered magnets and permanent magnets that are in ion pumps. Fields are nominally only hazardous to people who have heart pacemakers. The likelihood of the fringe field causing a malfunction to the pacemaker is reduced by work planning, warnings in the hazard specification sheet, and warnings at all Linac entry points about this hazard.

III-1.2.9 Other Hazards

The Linac presents other hazards in the form of a list of checked off hazards shown in Table 2. All other hazards present in Linac areas are in the form of Standard Industrial Hazards discussed in SAD Section I, Chapter 04.

III-1.2.9.1 Confined Spaces

Confined spaces in the form of DTL RF cavities are present in the Linac tunnel. These are accessed for maintenance and inspection purposes by personnel trained in confined space entry. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I, Chapter 04 Safety Analysis. Work in Linac involving confined spaces implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.9.2 Noise

Operating cooling water systems creates a potential noise hazard in the lower Linac gallery. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I, Chapter 04 Safety Analysis. Work in Linac involving high levels of noise implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.9.3 Silica

Silica dust may be created when drilling into concrete floors or walls. Silica hazards have been evaluated within the common Risk Matrix table included in SAD Section I, Chapter 04 Safety Analysis. Work in Linac involving silica dust implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.9.4 Ergonomics

Both office and technical work in Linac areas may involve: sitting or standing for long periods, repetitive motion, cramped conditions, and other ergonomic concerns. Ergonomic hazards have been evaluated within the common Risk Matrix table included in SAD Section I, Chapter 04 Safety Analysis. Work in Linac involving ergonomic concerns implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.9.5 Asbestos

Access penetrations connecting the Linac gallery to the enclosure tunnel are asbestos lined due to common fire prevention practices during the period when the building was constructed. Dues to the age of the building, asbestos may be present in other areas as well. The asbestos penetrations have been evaluated within the common Risk Matrix table included in SAD Section I, Chapter 04 Safety Analysis. Work in Linac involving asbestos implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.9.6 Working at Heights

Linac technicians utilize ladders, step stools, and mobile work platforms to conduct maintenance in Linac areas. Utilizing fall protection equipment, trained personnel may work on top of equipment where there is a chance of falling. Work at height has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Working at heights in Linac areas implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.10 Access & Egress

The Linac presents access and egress hazards in the form of a list of checked off hazards shown in Table 2. All other hazards present in Linac areas are in the form of Standard Industrial Hazards discussed in SAD Section I, Chapter 04.

III-1.2.10.1 Life Safety Egress

The Linac tunnel has access and egress points at both the north and south ends of the tunnel. Both the upper and lower Linac gallery have multiple points of entry. Life safety egress in Linac areas has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in Linac involving egress hazards implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.11 Environmental

The Linac presents environmental hazards in the form of a list of checked off hazards shown in Table 2. All environmental hazards present in Linac areas are in the form of Standard Industrial Hazards discussed in SAD Section I, Chapter 04.

III-1.2.11.1 Hazard to Air

N/A.

III-1.2.11.2 Hazard to Water

Transformer oil found in Linac RF sources has the potential to leak or spill and spread contamination. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in Linac involving transformer oil implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-1.2.11.3 Hazard to Soil

N/A.

III-1.3. Summary of Hazards to Members of the Public

Under normal operating conditions, the Linac is not hazardous to members of the public. Defense in depth exists in the form of active and passive controls sufficient to contain hazards even during unforeseen events.

III-1.4. Summary of Credited Controls

III-1.4.1 Passive Credited Controls

Passive controls are elements of facility design that require no action to function properly. These are fixed elements of the beam line that take direct human intervention to remove. The Linac enclosure is designed and constructed as a permanent concrete and earth-covered radiation shield that uses a combination of permanent shielding, movable shielding, penetration shielding, and Radiation Area fences to protect personnel from radiological exposure during beam operations.

III-1.4.1.1 Shielding

III-1.4.1.1.1 Permanent Shielding Including Labyrinths

The permanent shielding encompasses the structural elements surrounding the beam line components and extraction lines. The concrete structure is contiguous with the Linac and includes an upstream equipment access area, a personnel access labyrinth at the 400 MeV area with one exit, utility penetrations, and earthen berms and overburden.

The permanent shielding and shielding efficacy have been quantitatively analyzed for the enclosure and documented in the Linac Shielding Assessment. For normal operating conditions, the enclosure has sufficient earth overburden such that radiation levels on the top of the berm and in the lower level Linac equipment area are less than 5 mrem/hr and less than 0.25 mrem/hr at the ground floor level of the enclosure. Interlocked radiation detectors limit the duration of accident conditions to short periods of time and the accidental dose rates to less than 100 mrem/hr on top of the berm and in the lower level Linac gallery and less than 5 mrem/hr on the Linac ground floor level.

III-1.4.1.1.2 Movable Shielding

The Linac has no areas with movable shielding to outside areas. An equipment access hatch, midway between the Linac and ITA experimental hall, was previously used for lowering equipment into the 400 MeV end of the Linac enclosure. The equipment access hatch has been filled with concrete blocks. These blocks now separate the Linac enclosure and the ITA experimental hall. The concrete block wall is considered permanent shielding.

III-1.4.1.1.3 Penetration Shielding

The Linac enclosure has several utility and RF waveguide penetrations routing between the exclusion areas and occupied areas which were analyzed [1, 2] for required shielding. Each of the original nine Linac accelerating tanks has three 30-inch penetrations passing from the lower level gallery into the Linac tunnel. These penetrations have concrete shielding installed in front of, and in, the penetrations. An interlocked radiation detector has been placed just above the RF transmission line at the middle penetration which is the weakest link for shielding to insure accident condition beam losses result in an accidental dose rate of less than 100 mrem/hr in the Linac lower level.

The upper waveguide penetrations for the 400 MeV Linac upgrade waveguides that are downstream of the NTF treatment room pass through the top of the linac gallery and enter the Linac enclosure through vertical penetrations in the Linac berm. These vertical penetrations are also protected by the interlocked radiation monitors in the Linac lower level above the RF transmission lines. The Linac lower level interlocked radiation monitors will limit beam losses in the Linac from 1% to 10%, therefore preventing the dose rates from the upgrade penetrations from exceeding 3 mrem/hr. In summary, the prompt dose rates at the exits of the penetrations are within the limits established in the FRCM.

III-1.4.1.2 Fencing

III-1.4.1.2.1 Radiation Area Fencing

Fences are used and posted to designate potential Radiation Areas during machine operations. The MuCool Facility Shielding Assessment [8] concluded that the radiation levels along the MTA beamline require radiation fences. The entire Linac berm along with the MTA beamline was fenced and posted consistent with its identification as a Radiation Area in accordance with the FRCM. The Linac shielding assessment identified three small areas near the NTF in the Linac lower level that are also fenced and posted as Radiation Areas during NTF operations.

III-1.4.2 Active Engineered Credited Controls

Active engineered controls are systems designed to reduce the risks from accelerator operations to an acceptable level. These are automatic systems that limit operations, shut down operations, or provide warning alarms when operating parameters are exceeded. The active controls in place for Linac operations are discussed below.

III-1.4.2.1 Radiation Safety Interlock System

The Linac enclosure employs a Radiation Safety Interlock System. The characteristics of the system are described in Section I of the Fermilab SAD.

There are two entrances to the Linac enclosure: one interlocked gate on the north side of the enclosure and one interlocked door located at the south end of the enclosure. The interlock system inhibits transport of beam beyond the Linac 400 MeV extraction point to the Booster or MTA and inhibits RF power to the DTL and CCL cavities.

The Linac utilizes chipmunk and scarecrow radiation detectors located at the north end of the enclosure, at the 400 MeV labyrinth area, outside the enclosure at each of the RF transmission line penetrations, and on the berm above the two beam absorbers. When personnel access the Booster accelerator, two additional detectors are enabled in the Booster Chute area, the area where the Linac Beam is injected into the Booster accelerator. The detectors monitor radiation levels to protect personnel by disabling the beam should prompt radiation from operations exceed specific limits.

The Radiation Safety Interlock system inhibits beam by controlling redundant critical devices. In the case of Linac, the primary critical device is the 120V supply for the injector beam valve (L:LVV), the second is the power supply to the low-level amplifier used by the RFQ (L:RFQDS1). In the event of a critical device failure, the system has a failure mode function which disables the 480V contactor for the extractor power supply that will inhibit beam to the Linac.

Trained and qualified personnel from the AD Operations Department are required to search and secure the enclosure before permits from the radiation safety interlock system may be reestablished following any personnel access to the enclosure, except under strictly specified controlled access conditions. The Radiation Safety Interlock Systems including requirements for hardware and system testing, inventory of interlock keys, search and secure procedures for the beam line enclosure, controlled access procedures, personnel training requirements, and procedures for maintenance of interlock systems, are in conformance with the requirements stated in the FRCM.

III-1.4.2.2 ODH Safety System

This hazard is not applicable to this area.

III-1.4.3 Administrative Credited Controls

All Linac accelerator operations with the potential to affect the safety of employees, researchers, or the public, or to adversely affect the environment, are performed using approved laboratory, division, or department procedures. These procedures are the administrative controls that encompass the human interactions that define safe accelerator operations. The administrative procedures and programs considered necessary to ensure safe accelerator operations are discussed below.

III-1.4.3.1 Operation Authorization Document

Beam will not be transported to the Linac beam line without an approved Beam Permit and Run Condition. The Beam Permit specifies beam power limits as determined and approved by the AD director in consultation with the ESH Department Head, RSO, AD/BD Operations Department Head, and AD/BD Proton Source Department Head. The Run Conditions list the operating modes and safety envelope for the Linac. Run Conditions are issued by the ESH department, and are signed by the AD/BD Operations Department Head, RSO, and AD/BD Head.

In order to run beam to the Linac, the radiation and electrical safety interlock systems must be active, the Linac enclosure must be searched and secured; the critical device Linac Vacuum Valve (accelerator control system name L:LVV) must be open and the Linac RFQ (accelerator control system name L:RFQDS1) must be energized.

III-1.4.3.2 Staffing

Commissioning, normal operations, and emergency management of the Linac are all conducted under the auspices of the AD Headquarters, the ES&H Department, and the AD Operations Department in accordance with the Fermilab SAD.

III-1.4.3.3 Accelerator Operating Parameters

The Linac is assessed for a beam current of 35 mA for 30 μs at 15 Hz with a maximum kinetic energy of 400 MeV. This results in an operating envelope of 3.54 x 10^{17} protons/hour, at 400 MeV. The current operating envelope beam power limits exceed future laboratory programmatic goals.

III-1.5. Defense-in-Depth Controls

Under normal operating conditions, the Linac is not hazardous to members of the public. Defense in depth exists in the form of active and passive controls sufficient to contain hazards even during unforeseen events.

III-1.6. Machine Protection Controls

The Linac is protected by beam loss monitors, vacuum monitors, and RF leak detectors.

III-1.7. Decommissioning

DOE Field Element Manager approval shall be obtained prior to the start of any decommissioning activities for the Linac.

III-1.8. Summary and Conclusion

Specific hazards associated with commissioning and operation of the Linac accelerator are identified and assessed in this chapter of the Fermilab SAD. The designs, controls, and procedures to mitigate Linac-specific hazards are identified and described. In addition to these specific safety considerations, the Linac accelerator is subject to the global and more generic safety requirements, controls and procedures outlined in Section 1 of this Fermilab SAD.

The preceding discussion of the hazards presented with Linac accelerator operations and the credited controls established to mitigate those hazards demonstrate that the Linac can be operated in a manner that will produce minimal risk to the health and safety of Fermilab workers, visiting scientists, the public, as well as to the environment.

III-1.9. References

[1] Fermilab Radiological Control Manual
[2] C. Schmidt, T. Kroc, L. Allen and E. McCrory, *Radiation Shielding Assessment of the Linac Enclosure, 26 April* 1991.
[3] C. Schmidt and T. Kroc, *Radiation Shielding Assessment of the Linac High Energy Enclosure Following the 1993 Upgrade Installation and Low Intensity Commissioning, September* 1993.
[4] J. Cossairt, *Use of a Concentration-Based Model for Calculating the Radioactivation of Soil and Groundwater at Fermilab, December* 1994.
[5] J. Cossairt, A. Elwin, P. Kesich, A. Malensek, N. Mokhov and A. Wehmann, *The Concentration Model Revisited, 24 June* 1999.

[6] L. Allen, F. J., F. Garcia, M. Gerardi, B. Higgins, K. Vaziri, G. Lauten, A. Lee, D. Newhart, B. Ogert, I. Rakhno, R. Reilly and D. Reitzner, *Linac Momentum Beam Dump Vacuum, November* 2011.

[7] R. Lewis and D. Bollinger, *Flammable Gas Risk Calculation and Installation Requirements For Commissioning and Operation of the RFQ Ion Source in the I- Pit (October 2012 Configuration), October* 2012.

[8] C. Johnstone, I. Rakhno, N. Mokhov and W. Higgins, MuCOOL Facility Shielding Assessment, 2010.

III-1.10. Appendix – Risk Matrices

Risk Assessment methodology was developed based on the methodology described in DOE-HDBK-1163-2020. Hazards and their potential events are evaluated for likelihood and potential consequence assuming no controls in place, which results in a baseline risk. A baseline risk (i.e., an unmitigated risk) value of III and IV does not require further controls based on the Handbook. Events with a baseline risk value of I or II do require prevention and/or mitigation measures to be established in order to reduce the risk value to an acceptable level of III or IV. Generally, preventive controls are applied prior to a loss event, reflecting a likelihood reduction, and mitigative controls are applied after a loss event, reflecting a consequence reduction. For each control put in place, likelihood or consequence can have a single "bin drop", resulting in a new residual risk (i.e., a mitigated risk). This risk assessment process is repeated for each hazard for Facility Workers (FW), Co-Located Workers (CLW), and Maximally-Exposed Offsite Individual (MOI). At the conclusion of the risk assessments, controls that are in place for the identified accelerator specific hazards are identified as Credited Controls and further summarized in Section III-1.4 of this Chapter as well as SAD Chapter VII-A.1 *Accelerator Safety Envelope – Fermilab Main Accelerator*.